CHAPTER 12

Colliding Beams Mode

Chapters 1 through 8 have provided pieces to a puzzle, a large one at that. Chapter 9 brought a lot of those pieces together. For example, in chapter 2 you learned that a TeV dipole is part of a cell, which contains 8 dipoles and 2 quadrupoles. In turn, that cell is part of a FODO lattice, which repeats all the way around the ring except at certain locations. Before establishing any current in a superconducting magnet the cryogenics must bring the temperature of the NbTi bus to T_c. The satellite refrigerator building pulls helium gas from the discharge line, cools it via the heat exchanger and wet engine, and then sends it through the magnets. Once the temperature of the superconducting magnets reaches T_c, the power supplies at the 2 and 3 service buildings can supply current to the bus. The current plays out on a predetermined ramp that is loaded into TECAR from the console page C49 in the MCR. The ramp changes the field in the magnets so that the protons and antiprotons will feel the appropriate force to keep them in the beam pipe as the energy increases from 150 GeV to 980 GeV.

Lets not lose sight of what the final picture is in this mode. The results are p and pbar collisions that produce high quantities of rare, massive particles for study.

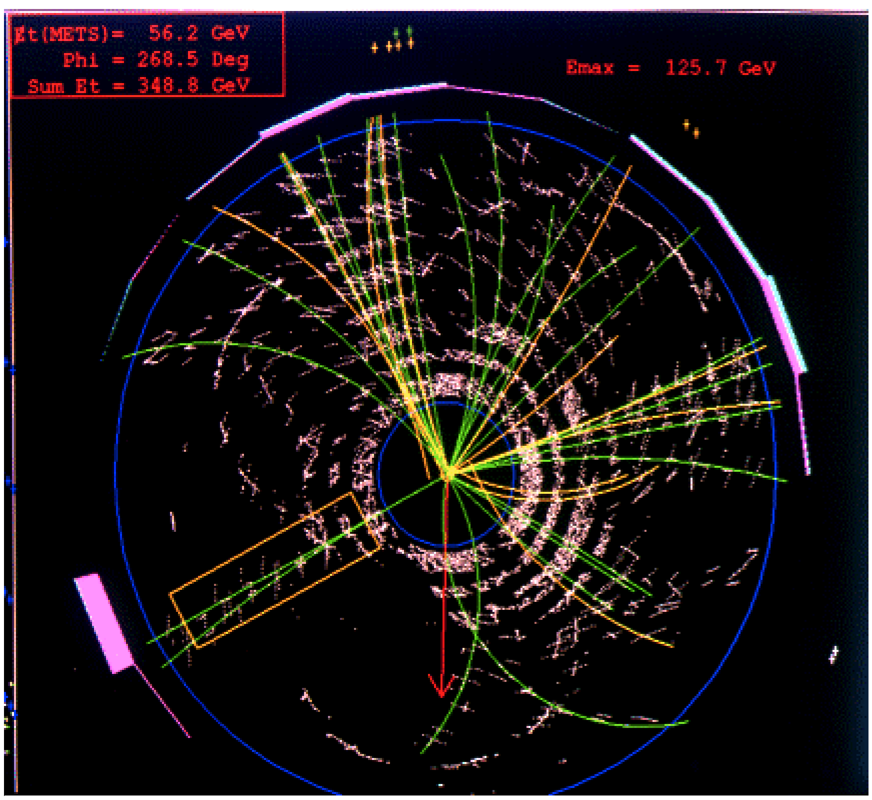


Figure 10.1 A detected top-antitop quark event.

A Shot Setup

In the collider run Ib a shot setup took about 2.5 hours to complete. Run II hopes to achieve an average shot setup of about ½ hour. The motivation is that this will increase the integrated luminosity by roughly 20%. How is this possible, you say? The plan is to automate most of the setup with sequencers.

There are 5 major steps to a shot setup:

1) Tune up P1 and A1 lines
2) Inject proton and antiproton bunches
3) Accelerate to 1 TeV
4) Initiate a low β squeeze
5) Begin colliding and scrape away beam halo

Let's take a look at these steps individually.

1) Tune up P1 and A1 lines

Before injecting protons and antiprotons destined for a store, the transfer lines into the TeV must be tuned up so that beam is placed onto the injection closed orbit with the least amount of losses so as to preserve emittance. To do this the sequencer aggregate *goto proton inj porch* sets the TeV ramp at 150 GeV. This is when shot setup officially begins. The P1 line is tuned up first. The Pbar sequencer loads the TLG with a timeline, which contains, among other things, the modules *Collider protons to Tevatron* and *Pbars from Accumulator to Tevatron.* Next, the TeV sequencer aggregate *proton injection tune up* injects beam into the TeV via the event sequence of $2B $4D. Beam enters the Main Injector, accelerates to 150 GeV, is extracted to the P1 line, enters the Tevatron, and is aborted at C0.

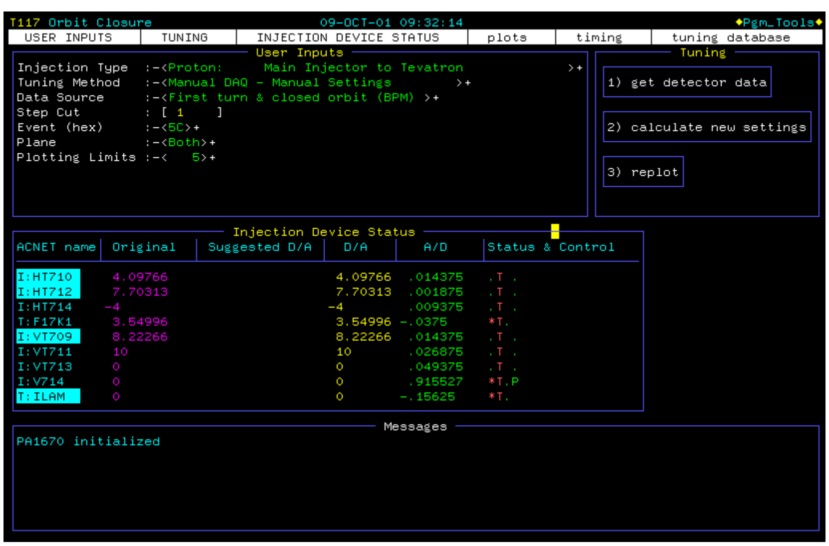


Figure 10.2 T117 closure program for proton injection.

To determine if the protons have been correctly injected onto the closed orbit, the Injection Closure program on T117 will take data on the first turn flash and the display when the $78 is broadcast. The program will calculate a change in current settings to trims I:HT710 and I:HT712 for the horizontal direction and trims I:VT709 and T:ILAM for the vertical direction, which will place the protons on the proper injection closed orbit.

Once the P1 line positions are set, the A1 line has to be tuned up. Since antiprotons are an expensive commodity, the line is tuned with reverse protons via the *reverse injection tune up* aggregate. The sequencer turns on the separators so that the injection helix is present but with the opposite polarity for mimicking the pbar helix. An event sequence of $2B $4D is initiated, which injects 150 GeV protons through the P1 line and into the TeV. Once the protons have settled onto the Pbar closed orbit an event sequence of $2A $5D is broadcast and the protons are extracted out through the F0 lambertson. The protons exit the A1 line at MI-62 and go on to the MI-40 abort. T117 is used to calculate the strengths of the I:HT902 and I:HT904 trims for the horizontal direction and I:VT901 and I:VT903 for the vertical direction so that the proper closed orbit can be attained.

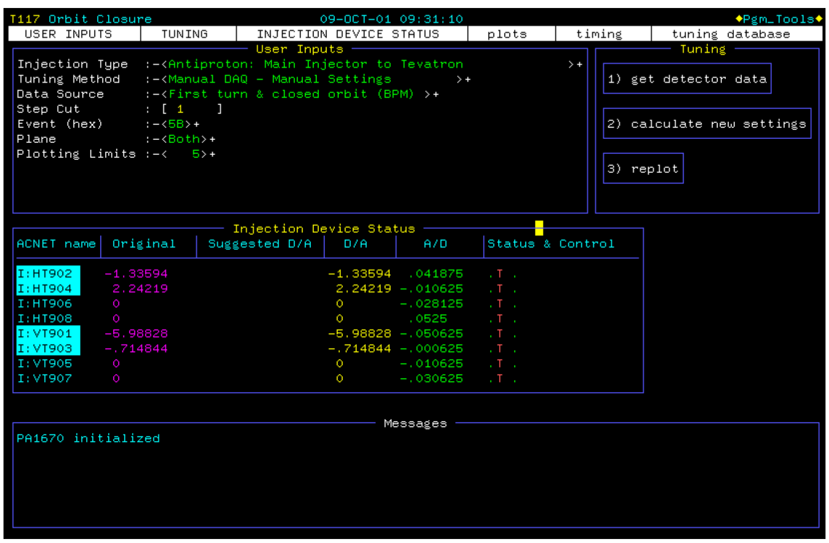


Figure 10.3 T117 closure program for reverse injection tune up.

2) Inject Proton and Antiproton Bunches

With the Tevatron at 150 GeV, 36 coalesced proton bunches are injected via the P1 line. The proton bunches are injected one at a time with each bunch spaced 21 RF buckets (396 ns) apart. There are 3 "trains" of 12 bunches and between each train is an abort gap of 2.617 µsec (139 buckets).

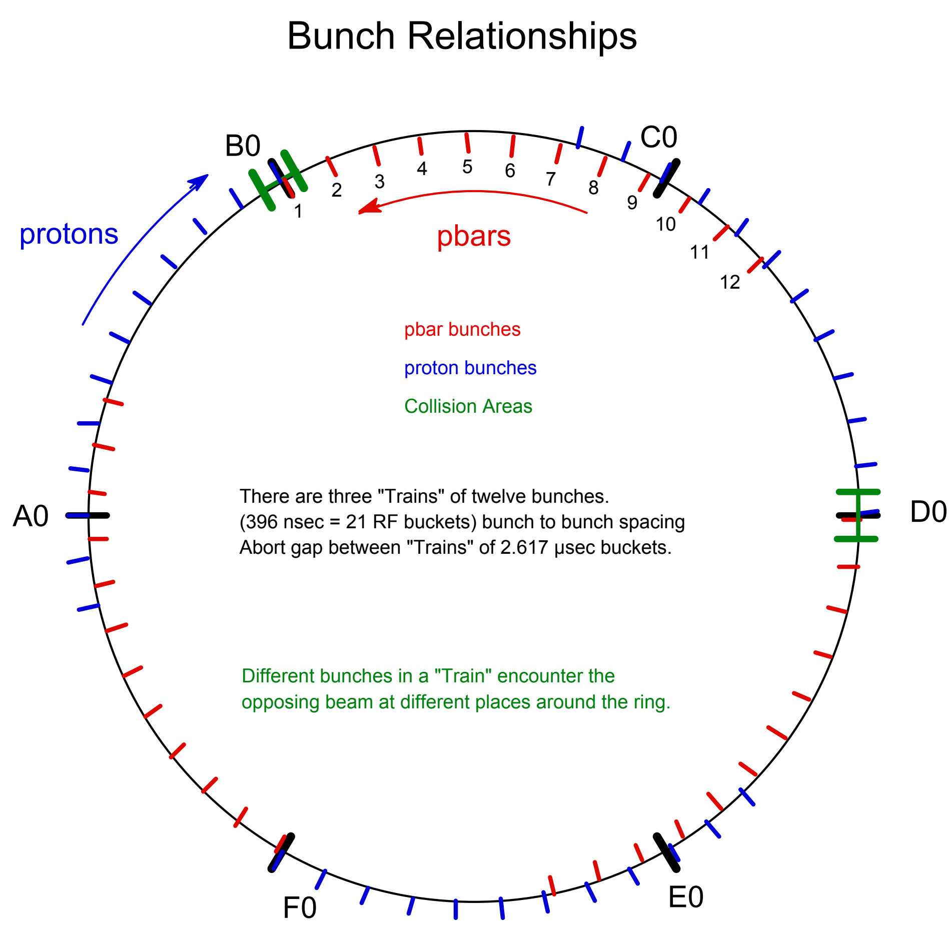


Figure 10.4 Bunch and train spacing of the protons and pbars around the Tevatron.

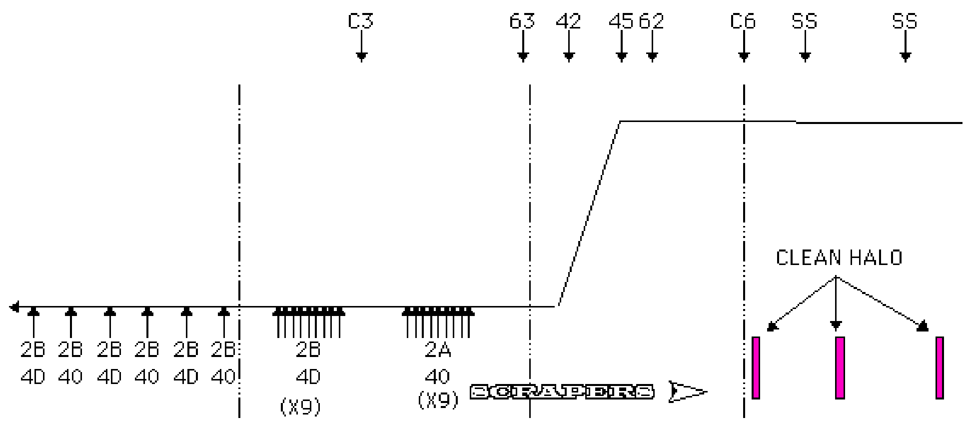
Just as with the tune up of the P1 line, the Pbar sequencer loads into the TLG timeline *Load Collider Protons*, which contains the event sequence $2B $4D on a short supercycle so that injection of the bunches is done quickly. The TeV sequencer aggregate *inject final protons* is started and the Tevatron is loaded with 36 coalesced proton bunches. If any portion of the proton bunch intensity or emittance is undesired, then the TeV beam can be aborted and the aggregate restarted. Once the proton intensity is satisfactory, then the antiproton bunches from the Accumulator or Recycler can be loaded into the TeV.

To begin loading antiprotons, the *setup pbar injection* aggregate must be run first. This aggregate, among other things, uses a set of electrostatic separators to create a pair of non-intersecting helical closed orbits with protons on one strand and the Pbars ready to be placed on the other. The Pbar sequencer sets up the TLG to play out timeline *Load Collider Pbars*. An event sequence of $2A $40 is initiated which causes 4 trains[†] of Accumulator pbars with a 21 ns bucket spacing to be extracted to the Main Injector. The Pbars are ramped to 150 GeV, coalesced, and then injected onto the TeV helical orbit via the A1 line. Each group of 4 bunches are placed, in order, into the buckets using the following scheme: A01-A04, A13-A16, A25-A28, A05-A08, A17-A20, A29-A32, A09-A12, A21-A24, A33-A36. Each bunch is 396 ns apart.

[†] There are 9 bunches of pbars in each train.

3) Acceleration to 980 GeV

Before accelerating both counter-rotating beams to 980 GeV, the sequencer aggregate *prepare to ramp* removes the F0 lambertson injection bump. The *accelerate* aggregate then turns on the high energy lead flows, and enables a $63 that initiates the TeV power supplies to ramp up.



During the acceleration to 980 GeV the tunes, coupling, and chromaticity are controlled to prevent beam loss and emittance growth.

4) Initiate a low β squeeze and collide

After the beam has reached 980 GeV, the sequencer aggregate *goto low beta* broadcasts a $C5 event that begins the low β squeeze. The current in the low β quadrupoles is ramped to reduce the β^* at the CDF and D0 interaction regions from 1.7 m to 35 cm. When the low β squeeze has reached about 0.5 m the injection helix is changed to the collision helix and separation bumps at the interaction points in the detectors are turned on.

Picture of low beta effect on the lattice

The *initiate collisions* aggregate is next. A $C6 event collapses the separation bumps at the interaction points and brings both beams into collision at the detectors. The separator helix is phased so that the proton and antiproton beams only collide at the center of the detectors.

5) Scrape away beam halo and level luminosity

When the beams are brought into collision and the luminosity begins to increase, the halo of protons and antiprotons needs to be scraped away in order to avoid both radiation damage to the detectors and numerous background events. The sequencer aggregate *remove halo* will begin to step in the scrapers while monitoring the losses from specified BLMs. Once the scraping algorithm determines the halo is no longer present the scrapers are moved out by 40 mils (1 mm).

The final aggregate is *HEP store*, which sets the time for the flying wires to periodically go through the beam to gather bunch structure information. Plots are also started to monitor the luminosity and losses at the detectors.

The main goal of Run II is to provide a luminosity of 2×10^{32} cm^{-2}sec^{-1} with 36X36 stores. Allowing for an interaction crossection of 45 mb, this yields an average of 5.8 interactions per crossing. The point is that as the luminosity increases, the performance of the detector decreases due to its particle tracking resolution. In order to maximize the performance, the luminosity per crossing is leveled to a specific value and then maintained at that value throughout the store. The leveling is achieved by continually varying the β function at the interaction region until it reaches its minimum, 35 cm.

Maintaining a Store